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THE CAGAOUARIC GRANITE AND PORPHYRY AND THEIR CONTACT EFFECTS.

THE CACAQUABIC GRANITE AND PORPHYRY AND THEIR CONTACT EFFECTS

BY

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A. B. University of Illinois, 1915
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Submitted in Partial Fulfillment of the Requirements for the

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY LUTHER EUGENE KENNEDY

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BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Luther Eugene Kennedy

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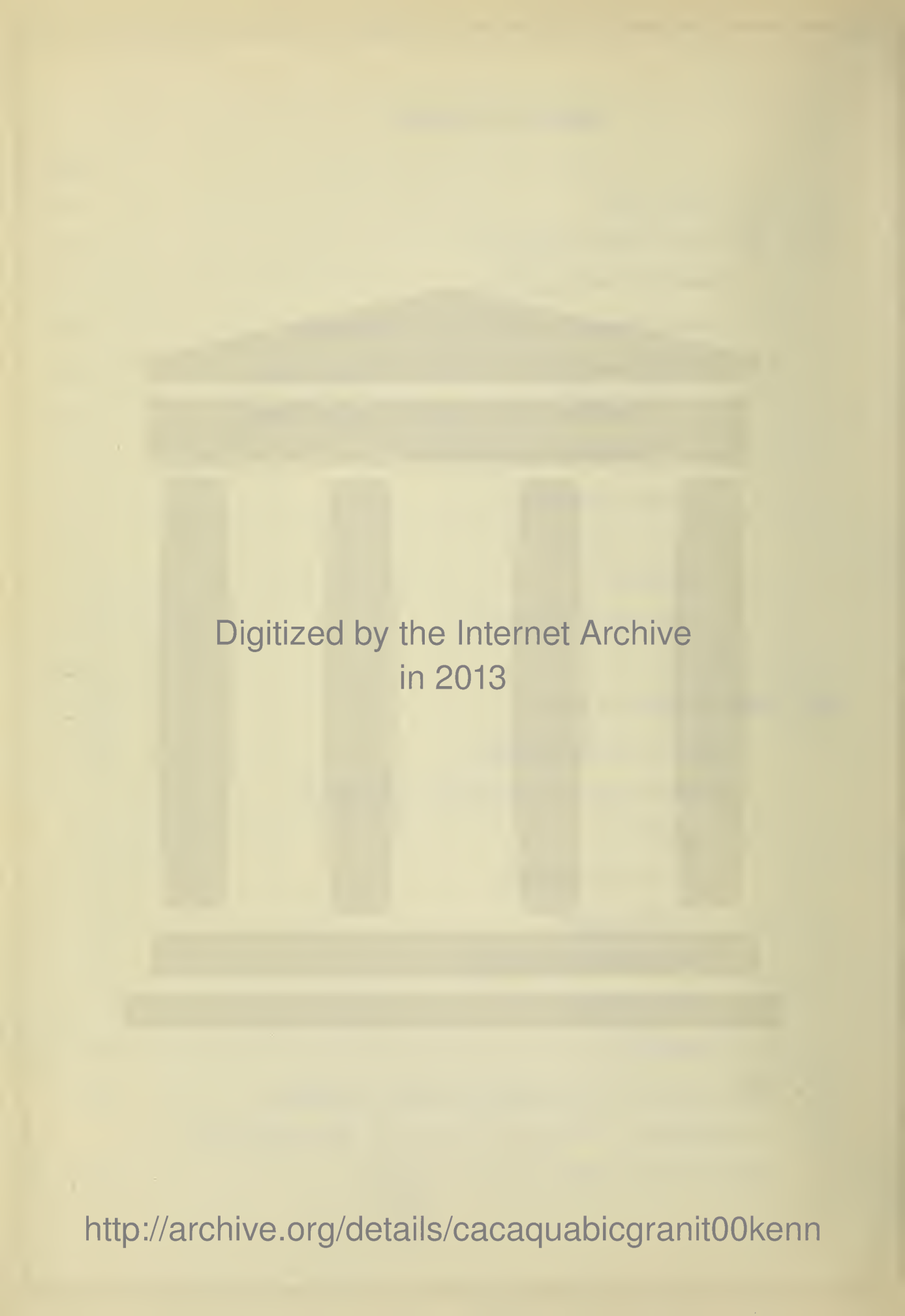
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I. INTRODUCTION

Cacaquabic Lake is situated in the northeastern part of Lake County in northeastern Minnesota toward the eastern end of the Vermilion Iron Range. It is about 95 miles north-northeast of Duluth and is about 30 miles east-northeast of Winton, the terminus of the Duluth and Iron Range Railroad. The Lake is reached from Winton by canoe via Fall, Basswood, Birch, Carp, Knife, Spoon and Pickle Lakes.

The stratigraphic column for the rocks in the Vermilion district is as follows:

Quaternary system	
Pleistocene series.....	Drift
Algonkian system	
Keweenawan series.....	Duluth gabbro and Logan sills
Huronian series	
Upper Huronian (Animikie).....	Rove Slate Gunflint formation
Middle and Lower Huronian.....	Intrusive rocks - granites, (Cacaquabic granite), granite porphyries, dolerites and lamprophyres. Knife Lake slate Agawa Iron formation Ogishkee conglomerate
Archean system	
Laurentian series.....	Granites of Basswood Lake and other intrusives

Keewatin series.....Soudan formation
Ely greenstone

Of the above formations five are represented in the vincinity of Cacaquabic Lake: Ogishkee conglomerate, Knife Lake slate, Cacaquabic granite and porphyry, Duluth gabbro and glacial drift. The distribution of the first four is represented fairly accurately on the accompanying map[1], Fig. I. A few scattered boulders and thin

[1] U. S. Grant, 21st Ann. Rept. Geol. Nat. Hist. Survey Minn., p. 59, 1893.

patches of drift represent the glacial deposits in this area.

The relief in the vicinity of Cacaquabic Lake is about 400 feet, but the average relief is nearer 200 feet. This relief finds its expression in rounded hills having a general northeast trend. The most notable exception to the well rounded hills is the rather steep bluff of conglomerate, on the south side of the lake in the central part of section 36, T. 65 N., R. 7 W., which rises 200 feet above the lake level.

The lake has an elevation of 1500 feet above sea level and the highest hill in its vicinity in the S. E. $\frac{1}{4}$ sec. 31, T. 65 N., R. 6 W. is 1920 feet. There are often swampy areas between the hills due to the very imperfect and immature drainage which has been changed very little since the withdrawal of the glaciers. The streams connecting the rock-basin lakes are short and carry very little sediment.

In consequence of severe glaciation there is very little soil but even this little supports a fairly dense growth of pine trees. Where the region has not been burnt over, the moss has accumulated

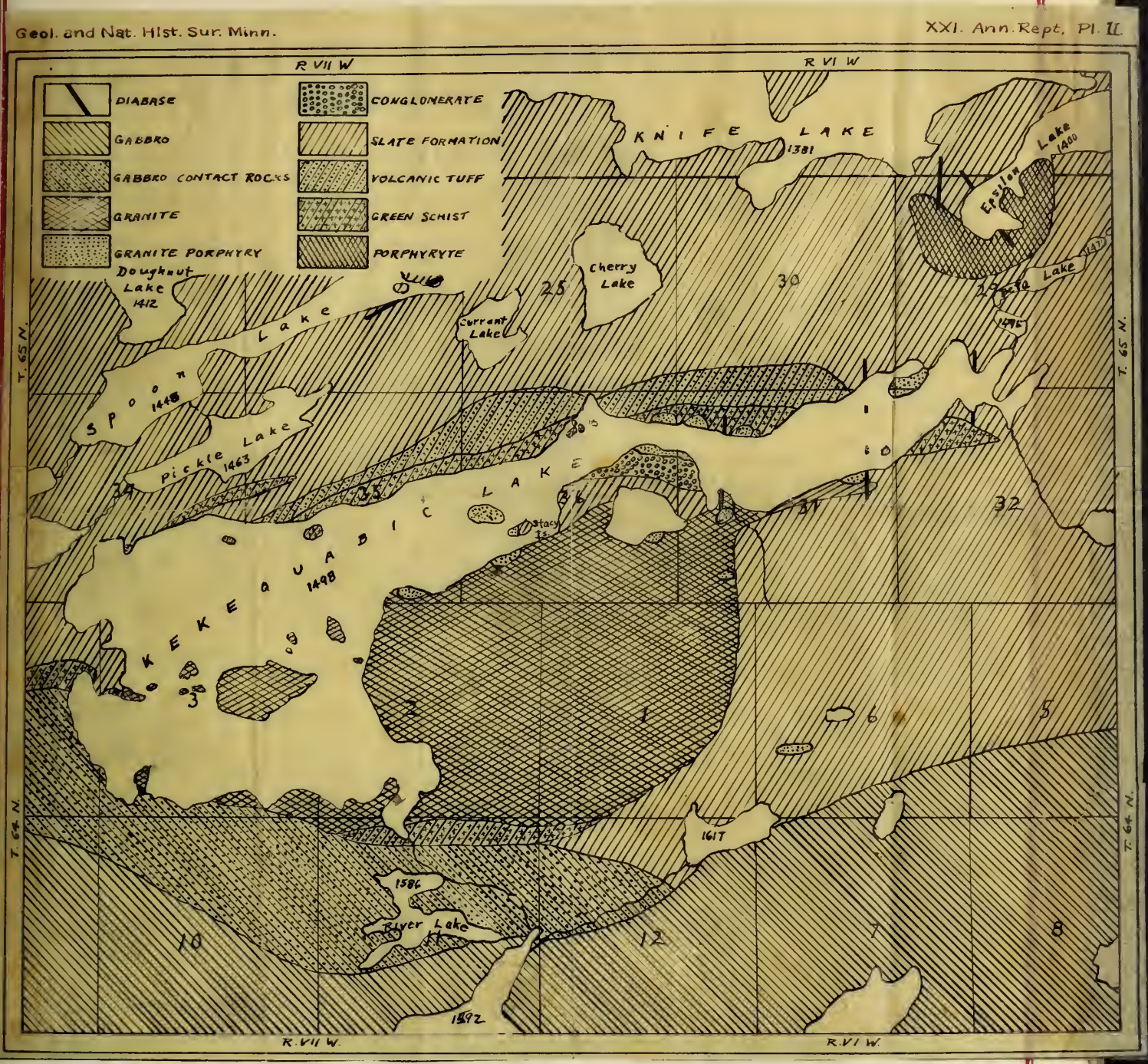


Fig. 1. - Map showing distribution of formations near Cacaquabic Lake.

to a thickness of several inches which makes it often difficult to find good exposures of rock.

The first geological work bearing on the Cacaquabic granite or porpnyry is a very brief description of a "peculiar" porphyry from the S. E. ¼ sec. 30, T. 65 N., R. 6 W., given in 1881 by N. H. Winchell.[1] This rock is described as having disseminated hornblende crystals in an amorphous groundmass.

[1] N. H. Winchell, 10th Ann. Rept. Geol. Nat. Hist. Survey Minn., pp. 92-93, 1881.

In 1887 M. E. Wadsworth[2] gave the following account of the same rock. "The section has a greenish gray groundmass, holding yellowish brown crystals of hornblende, epidote and greenish pseudomorphs of chlorite. ..... The chloritic pseudomorphs are composed of plates and scales of chlorite with some epidote, but whether they are pseudomorphs after hornblende or augite the writer cannot determine. The rock itself is an altered andesyte of the variety known as porphyrite or hornblende-porphyrite amongst lithologists."

[2] M. E. Wadsworth, Bull. No. 2, Preliminary Description of the Peridotytes, Gabbros, Diabases and Andesytes of Minn. pp.124-125, 1887.

Alexander Winchell[3] in the same year described several rocks with a porphyritic texture to which he gave the name of porphyrel. A specimen from the S. W. ¼ of the S. W. ¼ sec. 29, T. 65 N., R. 6 W., is described as follows: "It contains many crystals of feldspar which lie with their longer axes in the same direction. Some have a definite crystalline form in the center, with an imperfect

[3] A. Winchell, 15th Ann. Rept. Geol. Nat. Hist. Survey Minn., pp.148-156, 1887.

crystalline envelope. Some hold a dark mineral, apparently hornblende or chlorite in the center. The rock contains also green, chlorite-looking lumps and dark eightsided prisms - also traces of epidote. The rock further includes pebbly forms obscurely isolated and themselves porphyritic."

In making a summary of his observations on the rocks of the Vermilion iron bearing district Winchell[1] makes the following state-

[1] A. Winchell, 15th Ann. Rept. Geol. Nat. Hist. Survey Minn., pp. 179-180, 1887.

ment in regard to the term porphyrel: "I use this term to designate a rock which at first appears like a true porphyry. ... But it is not an eruptive rock. ... Characteristic as it might seem to be, it is only an ancient fragmental formation, which by secondary action, has altered the chemical and mineralogical arrangements of the constituents, until its aspect has been completely transformed, and its history almost lost."

In the same year N. H. Winchell[2] recorded a few observations on

[2] N. H. Winchell, 15th Ann. Rept. Geol. Nat. Hist. Survey Minn., pp. 361-369, 1887.

some of the rocks of the region. "At the southeast end of Kekebebic[Cacaquabic]Lake in sec. 11, T. 64 N., R. 7 W., is a rock speckled with light flesh-red crystals apparently of orthoclase. It is subcrystalline throughout, but its grained color is gray. It is another illustration of recrystallization of the sedimentaries in the vicinity of disturbance. This was apparently a graywacke at first. The same rock extends along the south shore of Kekebebic Lake through secs. 2 and 3, but becomes more and more red and syenitic. .. The aspect in general is that of a thin bedded gneissic

(syenitic) rock. .... On the island near the center of sec. 3, T. 64 N., R. 7 W., a bedded structure is brought out to view by weathering and is not that of sedimentation, only so far as its direction may have been due to that cause. It is now rather the coarse undulating bedding that is often seen in igneous rocks, that have been in flow. This dips about 25°N. and is crossed by joints that give it a coarsely columnar aspect when viewed from certain directions. The most westerly island is represented by a reddish syenite which was a fragmental rock originally. On the north side of this island the rock is less red and grayish green though still having some red orthoclase mingled with it porphyritically. This shows a nearer approach to the original grayish sedimentary condition. It is sparingly spotted with what appear to be forms of boulders and pebbles due to an original conglomerate condition. It is a firm rock with free quartz, sub-crystalline and apparently a mixed syenitic metamorphism after some graywacke.

"There is visible sometimes not only a conglomeratic, but a sedimentary, banded structure, dipping 80°from the horizon, south 10° west. Yet the most conspicuous bedding is that which dips 30° to 40° N.,10° E. ... This somewhat undulating north dipping bedding is what I have called sometimes provisionally a flowage structure, and it may be due to that, since when it is most developed the sedimentary banding is invisible.

"At the narrows of Kekebebic Lake, which is at the town line between T. 65 N., Rs.6 and 7 W.,is the porphyry rock. .. The porphyry which acts the part of an igneous rock, is evidently a condition of the slate conglomerate after fusion, and comes up like an eruptive rock through the green, hardened graywacke."

The following year N. H. Winchell[1] again visited this region.

[1] N. H. Winchell, 16th Ann. Rept. Geol. Nat. Hist. Survey Minn., pp. 100-108, 1888.

His observations and conclusions on the gneiss and porphyry were as follows: "The porphyrel (porphyry) is plainly an extension of the same part of the Ogishkee conglomerate westward. The change which converted that conglomerate into this acid eruptive rock was subsequent to the deposition of the Animikie rocks and the disturbance that accompanied it involved the slates and other parts of the Animikie. .... In general, the conglomerate was not much moved out of its place, but was metamorphosed in situ, in some cases retaining some evidences of its mechanical sedimentary manner of deposition. In others it was protruded in bosses that now rise boldly above the general level, and in still others was caused to lie upon some parts of the green schists in the manner of an overflow or laccolitic eruptive. ... The gneiss is in the line of strike from the coarsely crystalline syenite area farther southwest, which appears on the east side of White Iron Lake, and which rises still farther southwest and constitutes what is called in these reports, Giants Range. .. This is an isolated, abrupt, syenite, or granite range and evidently is of eruptive origin in the same sense that this porphyry at Nekebebic Lake is: an acid eruptive later than the Laurentian originally from some strata of the earth's upper-crust and not from a deep source."

U. S. Grant[2] visited the Cacaquabic Lake region in 1893.

[2] U. S. Grant, 20th Ann. Rept. Geol. Nat. Hist. Survey Minn., pp. 69-82, 1893.

His views which represent a decided advancement over those previous-

ly stated may be summarized as follows: The rock in this area, which in former reports was called chloritic syenite and chloritic gneiss, is a pyroxene granite. It is well developed on the small points in the southwestern parts of secs. 2 and 3, on the large island in the eastern part of sec. 3 and on the hills east of the lake in sec. 2, T. 64 N., R. 7 W. The granite has in many cases an irregular layered appearance, but there is no difference in the composition of the various layers. On the small island just off the point of the S. W. ¼ of the N. W. ¼, sec. 3, T.64 N., R. 7 W., is a gray rock with a fine-grained granitic groundmass holding very small porphyritic crystals of pyroxene and larger feldspar crystals. This rock is described as a fine grained pyroxene granite porphyry. It is here in sharp contact with the black argillyte Knife Lake slate . This rock is found farther east in many places along the shore of the lake in secs. 35 and 36, T. 65 N., R. 7 W., and in secs. 31 and 32, T. 65 N., R. 6 W. In some instances there is a parallel arrangement of the phenocrysts in the porphyry. Inclusions of dark chloritic material are present in both the porphyry and the granite. The granite and the porphyry were traced to within 150 feet of each other, but there was no indication of a gradation between the two.

In 1893 U. S. Grant[1] gave a rather detailed description of the granite and porphyry. He states that: "The granite is found in two facies, a granitic and a porphyritic, which seem to be rather distinct from each other in their field relations and in hand specimens, but in reality they are very closely related, undoubtedly

[1] U. S. Grant, Note on an augite soda-granite from Minnesota: American Geologist, Vol. XI, pp. 383-389, 1893.

forming parts of the same mass. ... The minerals composing the granite are feldspar (mostly anorthoclase), quartz and augite with accessory hornblende, biotite, apatite, and sphene.

"On chemical analysis, the two facies are found to agree very closely. A noticeable fact brought out by these analyses is that in both cases the proportion of soda is very much larger than that of potash. Using the term "soda-granite" as a true granite in which the soda is in excess of the potash, this rock would belong to the series of soda-granites, which, while reported from several localities in Europe, have as yet been rarely found in America. .. The large proportion of soda finds expression in the composition of the augite as well as in that of the feldspar.

"On separating a powder of a fresh specimen of the granitic facies by means of Thoulet's solution, the larger proportion of the feldspar fell between 2.58 and 2.62, which would indicate that it was a mixture of the orthoclase and albite molecules, and the analysis of this feldspar --- shows that it belongs to the anorthoclase series with the composition $Or_5\ Ab_{14}\ An_1$. The specific gravity of several of the phenocrysts of the porphyritic facies of the rock was determined. It ranges from 2.59 to 2.60, which, together with the analysis of the whole rock, is sufficient proof of its being anorthoclase.

"The color of the augite is green, although there are parts of some crystals which are colorless, and entirely colorless individuals are rarely seen. ... Zonal structure is rather common; in such cases the center is colorless or of lighter color than the outer layers. ... A very typical fresh specimen of the porphyritic

granite was powdered and analyzed. .. Assuming that this represents an isomorphous mixture of the diopside, hedenbergite, acmite and fassaite molecules, and calculating their relative proportions, we get the result given below.

Diopside	47 per cent
Hedenbergite	27 per cent
Acmite	21 per cent
Fassaite	5 per cent

"Secondary hornblende is common and abundant in all the altered specimens of the granite, while original hornblende has been noticed in but three sections, and here it, together with the biotite, is as abundant as the augite. ... Apatite occurs sparsely --- and sphene is uncommon.

"There is reason to think that soda-granites will be found more extensively developed in the Lake Superior region than has heretofore been supposed."

In the same year Grant[1] gave a general description of the

[1]U. S. Grant, The geology of Kekequabic Lake in northeastern Minnesota, with special reference to an augite soda-granite: 21st Ann. Rept. Geol. Nat. Hist. Survey of Minn., pp. 5-58, 1893.

geology of the region about Kekequabic [Cacaquabic] Lake. He had apparently changed his opinion in regard to the relation of the granite and the porphyry[2], for he says: "The porphyritic facies

[2]U. S. Grant, Note on an augite soda-granite from Minnesota: American Geologist, Vol. XI, pp. 383-389, 1893.

occur in isolated bosses without the limits of the granite proper, and is usually separated from it by the country rock. In a few places the two facies approach near to each other, but are not seen in actual contact. Here no evidence of a transition between the two is seen, each retaining its own characters as near together as they

were exposed. Only one contact has been seen between the two facies of the granite; here in a small exposure branching vein-like forms of the granite porphyry cut the granitic facies. From this it would appear that the porphyritic facies is of some later date than the main mass of the granite. .. The writer is inclined to think that the porphyritic facies is of but little later date than the granitic facies, and perhaps was erupted before the complete cooling of the latter."

The writer wishes to acknowledge his indebtedness to Dr. M. L. Nebel and Mr. C. S. Ross for assistance in the field and for suggestions in the laboratory work; to Professor U. S. Grant of Northwestern University for valuable suggestions in the field; and to Professor W. H. Emmons of the University of Minnesota and Professor C. K. Leith of the University of Wisconsin for the loan of numerous thin sections. To Professor W. S. Bayley of the University of Illinois, under whose supervision the work was done, the writer is under special obligations for invaluable assistance and direction during the progress of the work.

II. THE CACAQUABIC GRANITE

General Description

Macroscopically, the typical granite from the central part of the granite mass of the Cacaquabic Lake region is a medium to fine-grained rock composed almost entirely of pink feldspar, with subhedral to anhedral outlines, and a minor quantity of dark femic minerals in irregular grains and patches. The abundance of the feldspar, which makes up from 80 to 90 per cent of the rock, and its occurrence in more or less subhedral form, tend to give the granite a sub-porphyritic appearance as seen in the hand specimen. The maximum diameter of the feldspar grains is about 2 mm., but the average diameter would be much less, probably about 1.00 mm. Femic minerals, which constitute a small proportion of the volume of the rock, usually 5 to 10 per cent, occur in more or less irregular grains, the small size of which makes their macroscopic determination difficult, although the inference is that they are either augite or hornblende, possibly with some magnetite.

Under the microscope the granite is seen to be composed of microperthite, albite, aegirite-augite, katoforite, quartz, magnetite, titanite, and apatite. Apatite was apparently the first mineral to separate from the magma, followed by magnetite and titanite. Katoforite crystallized out next and appears to be a little earlier than the aegirite-augite with which it is associated. The microperthite and albite followed the femic minerals, and quartz, the last mineral to solidify, filled in the interstices between the others.

An analysis (I) of a typical specimen of this granite, made by J. M. Lindgren of the University of Illinois, and that (II) quoted by Grant[1] are as follows:

Analyses of Granite.

	I	II
	%	%
SiO_2	65.16	66.84
Al_2O_3	15.88	18.22
Fe_2O_3	1.20	2.27
FeO	1.18	0.20
MgO	1.75	0.81
CaO	2.40	3.31
Na_2O	5.84	5.14
K_2O	5.60	2.80
TiO_2	0.24	-----
P_2O_5	0.07	-----
H_2O	0.66	0.46
Total	99.98	100.05

[1] U. S. Grant, Note on augite soda-granite from Minnesota, Amer. Geologist, Vol. XI., p. 383, 1893.

The normative minerals calculated from analysis (I), according to the method adopted by H. S. Washington[2], and their percentages are given in column I below. In column II is the norm calculated by Washington[3] from Grant's analysis.

[2] H. S. Washington, Chem. Anal. Igneous Rocks, Prof. Paper 99, p. 1162, 1917.

[3] Idem, p. 220.

Calculation of the Norms of the Cacaquabic Granite.

	I		II
Mineral	%	Mineral	%
Quartz	4.08	Quartz	17.88
Orthoclase	33.36	Orthoclase	16.68
Albite	49.25	Albite	43.49
Anorthite	0.56	Anorthite	16.40
Corundum	0.00	Corundum	0.60
Salic	87.25	Salic	95.05
Diopside	8.99	Diopside	0.00
Hypersthene	0.83	Hypersthene	2.00
Magnetite	1.86	Magnetite	0.70
Hematite	0.00	Hematite	1.76
Ilmenite	0.46	Ilmenite	0.00
Femic	12.14	Femic	4.46

I		II	
Mineral	%	Mineral	%
Femic	12.14	Femic	4.46
Salic	87.25	Salic	95.05
H_2O	0.66	H_2O	.46
Total	100.05	Total	99.51

Class I, Persalane — Class I, Persalane

Order 5, Perfelic, Canadare — Order 4, Quardofelic, Britannare

Rang 1, Peralkalic, Nordmarkase — Rang 2, Domalkalic, Toscanase

Subrang 3, Sodipotassic, Phlegrose — Subrang 4, Dosodic, Lassenose

A measurement of the quantitative relationships of the minerals in several sections of the granite made by the Rosiwal[1] linear mensuration method, as modified by Lincoln and Rietz[2], showed only a small variation in the proportion of the minerals present. The following mode, measured on four sections of a representative specimen, may be considered as typical of the central mass of the granite.

[1] Rosiwal, Verh. der k. k. geol. Reichsanstalt, pp. 143-175, 1893.

[2] Lincoln and Rietz, The Determination of the Relative Volumes of the Components of Rocks by Mensuration Methods, Ec. Geol. Vol. 8, No. 2, pp. 120-140, 1913.

Calculation of the Mode.

Mineral	%
Quartz	4.41
Feldspar	83.39
Aegirite-augite	7.10
Katoforite	3.01
Titanite	1.19
Magnetite	0.73
Apatite	0.17
Total	100.00

There is a very close correspondence between the mode and the norm calculated from Mr. Lindgren's analysis with only minor

exceptions which can be easily explained. The relationship between the mode and the norm is indicated in tabular form below:

Comparison of Mode and Norm.

Mineral	Mode %	Norm %
Quartz	4.41	4.10
Feldspar	83.39	83.69
Amphiboloids	10.11	9.88
Titanite	1.19	0.00
Magnetite	0.73	1.87
Ilmenite	0.00	0.46
Apatite	0.17	0.00
Totals	100.00	100.00

The quartz, feldspar, and amphiboloids check very closely. The ferrous iron and the titanium represented by ilmenite in the norm are combined with silica to form titanite in the mode. The percentage of titanium as determined in the chemical analysis is too small to form the percentage of titanite represented in the mode. If the amount of titanium is higher than that indicated in the chemical analysis, not only would the percentage of normative ilmenite which could be allotted to titanite be increased, but the aluminium oxide would be reduced so that normative acmite would be formed in place of anorthite. That a small percentage of the acmite molecule is present is indicated by the pyroxene which is an aegirite-augite.

A consideration of the norm calculated by Washington[1] from

[1] H. S. Washington, Chem. anal. Igneous Rocks, Prof. Paper 99, p. 220, 1917.

Grant's analysis brings out several points which throw doubt upon the correctness of this analysis. The percentage of silica is very high, and if more of the basic oxides are calculated as femic minerals, as they undoubtedly should be, the amount of

silica would be increased still more. The alumina exceeds the alkalies and calcium to such an extent that corundum is formed in the norm. Under these conditions all the calcium is calculated as anorthite and none is left to combine with magnesium and ferrous iron to form diopside. Since the granite contains from five to twenty percent of augite and hornblende, according to Grant[1],

[1]U. S. Grant, 21st Ann. Rept. Geol. Nat. Hist. Survey Minn., p. 44, 1893.

this is a rather serious discrepancy. Grant states that the augite of the granite contains twenty-one percent of acmite but acmite is formed only when the sum of the alkalies exceeds the alumina, in which case all the calcium would be free diopside.

Description of Individual Minerals.

ALBITE-SODA MICROCLINE INTERGROWTH:- Chemical and physical character - The accurate determination of the feldspars was rendered difficult by reason of a very fine microperthitic intergrowth which is characteristic of the central mass of the granite.

Specific gravity tests were made on finely crushed and screened granite from two typical specimens by means of Thoulet's solution and a Westphal balance. The specimens were crushed to pass through a sixty mesh screen and the finest powder sifted out through a ninety mesh. The material obtained in this way is uniform in size and should give accurate results. Specimen No. 774 was taken from the S. W. $\frac{1}{4}$ of the S. W. $\frac{1}{4}$, Sec. 1, T.64 N., R.7 W., and No. 771 was taken from the N. W. $\frac{1}{4}$ of the S. W. $\frac{1}{4}$ of the same section.

Specific Gravity of Feldspar Intergrowths in Cacaquabic Granite

No. 774

Specific Gravity	Wt. Grams	%
1. ----- > 2.602	.549	33.0
2. 2.602 - 2.594	.519	31.2
3. 2.594 - 2.584	.337	20.2
4. 2.584 - 2.568	.146	8.8
5. 2.568 < -----	.114	6.9
		100.1

No. 771

Specific Gravity	Wt. Grams	%
1. ----- > 2.745	.031	3.8
2. 2.745 - 2.625	.048	5.9
3. 2.625 - 2.622	.032	3.9
4. 2.622 - 2.614	.047	5.8
5. 2.614 - 2.602	.102	12.5
6. 2.602 - 2.595	.214	26.3
7. 2.595 - 2.585	.196	24.0
8. 2.585 - 2.576	.066	8.1
9. 2.576 - 2.550	.072	8.8
10. 2.550 - 2.545	.006	0.7
		99.8

These results indicate that the feldspar is a fine intergrowth rather than a single feldspar, since in the latter case, all of the material should separate out at a point corresponding to its specific gravity or at two or more distinct points according to the number of different kinds of feldspar present.

Condensed Table of Specific Gravities.

Specific Gravity	No. 774	No. 771
Sp. Gr. > 2.602	33.0	31.9
Sp. Gr. 2602 - 2.585	51.4	50.4
Sp. Gr. < 2.585	15.7	17.6

Since the material separating out with higher specific gravities contains about 15 per cent of quartz and femic minerals, the amount of feldspar with a specific gravity above 2.602 is reduced to about fifteen per cent. This indicates that the amount

of feldspar separating out with a specific gravity greater than 2.602 is equivalent to the proportion with a specific gravity less than 2.585. Reference to the diagram of specific gravities (Fig. 2) will show the proportion of material separating out for the range of specific gravities indicated. The apparent break in the curve corresponding to an average specific gravity of 2.582 is due to the small differnce in the limits of specific gravity. In the case of material whose average specific gravity is 2.685, the upward trend is due not only to the wide range of the limits, but also to the fact that quartz, with specific gravity of 2.65, separates out within this range.

From a chemical analysis of the feldspar, separated by Thoulet's solution from the Cacaquabic granite, Grant calculated it to be anorthoclase with the composition $Or_5\ Ab_{14}\ An_1$, as previously stated.

Analysis of feldspar[1]

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O	Total
67.99	19.27	0.82	0.75	0.02	3.05	6.23	0.90	99.03

[1] U. S. Grant, 21st Ann. Rept. Geol. Nat. Hist. Survey Minn., p. 44, 1893.

Using the average specific gravities of orthoclase, albite and anorthite, the average specific gravity of a feldspar corresponding to $Or_5\ Ab_{14}\ An_1$ would be 2.615.

Mineral	Proportion	Sp. Gr.	Max.	Min.	Average
Orthoclase	5	2.54-2.56			
Albite	14	2.62-2.64	2.625	2.605	2.615
Anorthite	1	2.74-2.765			

That this is rather high for the average specific gravity of the feldspar in the Cacaquabic granite will be apparent from an

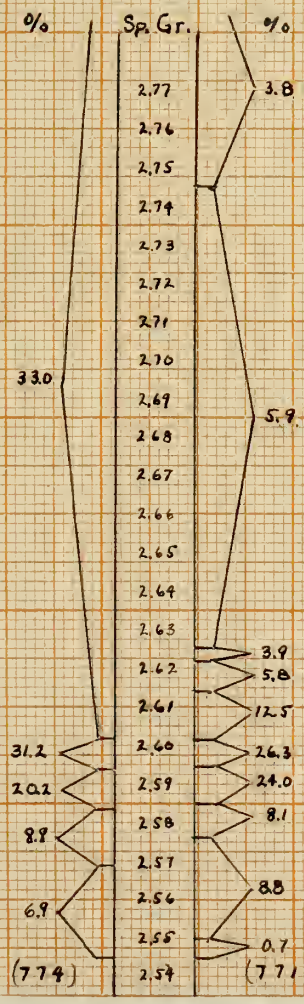


Fig.2. - Diagrams showing percentages of granitic material within certain limits of specific gravity.

examination of the tables and diagrams of specific gravities. In rock No. 771 less than 20 per cent of the material had a specific gravity greater than 2.614 and this included quartz and the femic minerals, while over 65 per cent had a specific gravity less than 2.602, the minimum specific gravity of the orthoclase-albite-anorthite ratio calculated by Grant. The actual average specific gravity of the feldspar in the Cacaquabic granite is between 2.595 and 2.60, which includes either a higher percentage of the orthoclase or microcline molecule or a decrease in the amount of the anorthite molecule present, if Grant's analysis of the feldspar, cited above, is assumed to be correct.

A calculation of the normative minerals from the feldspar analysis cited above gave the following results:

Mineral	%
Quartz	18.00
Orthoclase	18.35
Albite	52.92
Anorthite	3.89
Corundum	4.18
Hematite	0.76
	98.10
H_2O	.90
Total	99.00

The percentage of free quartz is abnormally large and renders the correctness of the analysis rather questionable. Grant stated that the silica percentage is larger than is required by the amount of soda, potash and lime present and explained it as due to the fact that a small amount of quartz was so intimately intergrown with the feldspar, that certain grains of the feldspar powder contained some quartz. In the case of an intergrowth of quartz and feldspar, it is conceivable that a small amount of quartz might be present in the separated feldspar, but where the intergrowth con-

sists of two feldspars rather than quartz and feldspar, it is difficult to understand how the separated feldspar powder could contain more quartz than is actually present in the rock, as indicated by the norm and mode. The excess of alumina over that needed for the formation of the feldspar molecules is also exceedingly high, giving 4.18 per cent of normative corundum, which also suggests that the analysis is incorrect.

Microchemical tests made on various samples of the feldspar powder separated by means of Thoulet's solution indicated a very high proportion of the soda molecule in all cases. A few grains of the feldspar were placed upon a balsam coated slide and covered with a drop or two of hydrofluoric acid. The acid attacks the feldspar forming fluosilicates of the bases which, upon evaporation, separate out in crystalline forms which are characteristic and easily recognizable. Sodium fluosilicate forms short hexagonal prisms, potassium fluosilicate crystallizes in cubes and octahedrons, and calcium fluosilicate is characterized by short prismatic monoclinic forms. Potassium fluosilicate occurred in much smaller proportion than the sodium salt in all of the samples, but there was an apparent increase in the amount of potassium with decreasing specific gravity of the feldspar. This indicates an intergrowth of albite with either soda-orthoclase or soda-microcline, since the last two have a specific gravity appreciably lower than the first. Calcium fluosilicate was not observed in any of the sections except those made from powder of high specific gravity, and then only in very limited quantity. The calcium probably resulted from decomposition of the femic minerals by the

hydrofluoric acid, as the material having a specific gravity above 2.625 is made up largely of particles consisting of feldspar and femic minerals in various proportions. These tests indicate that all the calcium molecule in the granite enters into the femic minerals. No appreciable amount of it enters into the feldspar to form potash oligoclase or anorthoclase as suggested by Grant, since no trace of the calcium fluosilicate was observable in tests made on pure feldspar powder. Calcium salts are more readily attacked by hydrofluoric acid than are either potassium or sodium salts and hence, if present in the feldspar, should appear as calcium fluosilicate in the section.

Optical properties - The feldspar grains are usually equidimensional or slightly elongated parallel to the "a" crystallographic axis. Their outline is subhedral, often approaching euhedrism, but modified around their edges by the suture-like interlocking of adjoining grains.

Their diameters range from almost submicroscopic dimensions to a maximum of 1.5 mm., but the diameter of most of the grains is .75 mm.

As seen in thin section, the feldspar is colorless but it appears rather turbid or cloudy in consequence of the presence of a dense fine-grained alteration product which is probably sericite or kaolin.

The most striking characteristic of the feldspar is the fine microperthitic intergrowth which is readily apparent in ordinary light with magnifications in excess of fifty diameters. The intergrowth occurs in thin wavy lentils that wedge out in short distances and are superseded by others. Where feldspar grains are in con-

tact with each other, there is an interweaving suture-like intergrowth along the margins of the adjoining grains that resembles somewhat the micrographic intergrowth of feldspar and quartz. The proportions of the two feldspars in the intergrowth are of the same order of magnitude.

Twinning according to the Carlsbad law is much more common than any other mode of twinning in the feldspar of the Cacaquabic granite. Albite twinning occurs in the central portion of some of the feldspar surrounded by an untwinned border having a lower index of refraction.

Zonal growth is observed occasionally although it is not a characteristic feature.

Addition of secondary feldspar is commonly noticed around the margins of the grains, especially where fracturing and corrosion have taken place. This new material occurs in crystallographic continuity with the older feldspar and is characterized by a fresh and unaltered appearance. It is distinct from the zonal arrangement which is primary.

Inclusions in the feldspars consist of magnetite, apatite, titanite, aegirite-augite, and katoforite. The magnetite, apatite, and titanite occur in about equal amounts and generally have well developed crystallographic outlines, although subhedral to anhedral grains of these minerals appear. Aegirite-augite inclusions are only sparingly present and katoforite is even less important. Gas or liquid inclusions were not visible with the highest magnifications used.

The index of refraction of the feldspars is in all cases lower than that of the Cacada balsam, 1.540. A list of the possible

feldspars with their respective indices follows:

Feldspar	Indices of refraction		
Orthoclase	1.519	1.523	1.525
Microcline	1.519	1.523	1.526
Soda microcline	1.523	1.528	1.529
Anorthoclase	1.523	1.528	1.529
Albite	1.529	1.532	1.539

By immersing finely crushed mineral fragments in benzonitrile with an index of 1.5261 and orienting them on one or the other of their cleavage surfaces, it was discovered that the direction of the intergrowth of the two feldspars is in all cases approximately parallel to the direction of vibration of the slow ray. By observing the movement of the Becke line when the three axes of elasticity were respectively parallel to the plane of vibration of the lower nicol, it was found that one of the feldspars making up the intergrowth had a higher index of refraction in all three positions. This, together with the fact that the feldspars all have a lower index of refraction than Canada balsam, indicates that the mineral is albite. The index of refraction of the other mineral in the intergrowth is higher in two directions and lower in the third, which places it as a soda-microcline. The refractive index of the benzonitrile was checked on a Fuess total reflectometer under the maximum variations in temperature to which the liquid might be subjected while in use, and it was found to vary only about three in the fourth decimal place. Such a variation would not vitiate the results in any degree. Blank tests were run on quartz and calcite crystals to make sure that the instrument was in proper working order.

The extinction angle on the feldspar in sections parallel to 010, measured from the trace of the 001 cleavage to the direction

of vibration of the fast ray, attains a maximum value of 20°. On sections parallel to 001 the extinction on the fast ray reaches 7°, although in the zone normal to 010 the extinction angles vary from 0°- 16° depending upon the orientation of the section. In this zone the extinction is measured from the trace of the 010 cleavage plane.

The optical character of the feldspar is positive in sections parallel to 010, with the plane of the optic axes parallel to the direction of vibration of the fast ray and perpendicular to the plane of intergrowth. On sections approximately parallel to 100 the feldspar is optically negative, with the plane of the optic axes perpendicular to the direction of vibration of the fast ray and parallel to the plane of intergrowth. Albite is optically positive with the acute bisectrix Z approximately perpendicular to 010, while soda-microcline is negative with the acute bisectrix X approximately perpendicular to 100. Since the positive acute bisectrix for albite corresponds to the obtuse bisectrix of soda-microcline and the planes of the optic axes of the two minerals are parallel, it follows that all sections parallel to 010 have a positive optical character. In like manner sections parallel to 100 are negative since this is the acute bisectrix for soda-microcline and the obtuse bisectrix for albite.

The plane of intergrowth of the feldspars is always approximately parallel to the slow ray. On sections parallel to 010, the direction of the intergrowth is about at right angles to the plane of the optic axes, and the angle from the intergrowth to the cleavage is 70°. The parameters of this plane of intergrowth are $\bar{9}01$, calculated from the crystallographic constants of albite. The

variation from the above intercepts, caused by taking the extreme values for the crystallographic constants of soda-microcline, tends to shift the value slightly toward $\overline{1}001$, while calculations based upon an average value agree almost exactly with those for albite.

Fracturing of some grains has taken place to some extent as evidenced by the irregular linear areas composed of fine-grained material showing aggregate polarization.

Corrosion of the feldspars is rather extensive. Most of the grains have a corroded appearance around their edges as though they had been attacked by the molten rock magma before its complete solidification. This solution later crystallized in the irregular pockets it had formed, and produced a minute interweaving or interlocking of the feldspar grains around their margins.

Practically all the feldspar grains show more or less alteration which gives them a cloudy or turbid appearance. The alteration sometimes is irregularly distributed throughout the grains, but usually it has a more or less definite arrangement. Thus it appears in irregular bands parallel to the intergrowth, or it spreads out from cleavage cracks. The minuteness of the particles of the decomposition products makes their determination impossible, but its appearance in reflected light suggests sericite or kaolin.

AEGIRITE-AUGITE:- The aegirite-augite in the Cacaquabic granite occurs with subhedral to euhedral outlines. The habit of the grains is prismatic with elongation parallel to the "c" crystallographic axis, which is characteristic of sodic pyroxenes.

Most of the grains are more or less irregular and do not show traces of well developed crystallographic planes, but frequently traces of well developed crystals are present. The prismatic faces parallel to the cleavages and to the ortho- and clino- pinacoids are well developed, but traces of pyramidal terminations are inconspicuous and rarely seen.

Cleavage is well developed parallel to the prismatic faces, as is indicated by the parallelism of the cleavage cracks to the elongation in the prismatic sections and their rectangular intersection in the basal sections. A parting parallel to the basal plane is sometimes present.

In size the aegirite-augite grains vary from those of submicroscopic dimensions to grains having a maximum diameter of 2 mm. The average diameter is about .5 mm, which is appreciably smaller than that of the feldspar grains, whose average diameter is .75 mm.

Zonal structure is absent. This is in marked contrast to the conspicuous zoning of the pyroxene in the porphyry which will be described later.

Inclusions in the aegirite-augite are common. The mineral which occurs in greatest abundance in this manner is katoforite. It is sometimes idiomorphic in outline but more often in irregular grains. Titanite in well developed crystal outlines and magnetite with euhedral form and in shapeless masses are next in order of decreasing quantity. Inclusions of apatite are rare. The larger pyroxene grains often enclose feldspar in a poikilitic manner.

The maximum extinction angle, measured from the trace of

the cleavage to the direction of vibration of the fast ray on sections parallel to the clinopinacoid, is 32°. Z∧c is then 58°, which indicates a pyroxene intermediate between augite and aegirite.

The color of the pyroxene in ordinary light is a pale olive-green. Pleochroism is distinct in various shades of green. Its pleochroism is: X= light olive green, Y = pale olive green, Z = greenish yellow, and the absorption is X>Y>Z.

The refraction of the aegirite-augite is rather high, which gives the mineral a rough appearance in thin section. The birefringence has a maximum value of about .032 which, in sections averaging about .02 mm. in thickness, gives blue to bluish-green colors of the second order. The minimum difference in indices of refraction X∧Y is about .010 and Y∧Z is .022. The dispersion is inclined with ρ>v.

Fracturing of the rock has broken some of the grains and the fragments are often arranged in an irregular manner along the plane of fracturing.

The pyroxene was corroded only slightly by the magma before complete crystallization, and it does not appear to have suffered any secondary corrosion. It is fresh in appearance in some cases, although in many instances it appears to be altering to serpentine, magnetite, epidote, lepidomelane, and secondary amphibole.

The aegirite-augite is associated more often with katoforite than with any other mineral. Often the two are intergrown or the aegirite-augite occurs as a border around the amphibole.

KATOFORITE:- The amphibole which occurs in the Cacaquabic granite is katoforite which is intermediate between hornblende and

the sodic amphiboles, arfvedsonite and riebeckite. It has euhedral to subhedral outlines indicating that it is of pyrogenetic origin. The habit of the crystals is prismatic with a slight elongation parallel to the "c" crystallographic axis, but the outlines of the grains are characteristically equidimensional. Unit prismatic faces are well developed but the pyramidal terminations are generally lacking.

The characteristic prismatic cleavage is present as indicated by the parallel cleavage cracks on the prismatic sections and the diamond-shaped cleavage pattern on the basal pinacoid.

The size of the katoforite particles varies from extremely small grains to those having a maximum diameter of about 1.0 mm., but the major proportion has an average diameter of .5 mm., which corresponds to the average size of the aegirite-augite.

Twinning is extremely rare, but in one case there was apparent twinning with the orthopinacoid as the twinning and composition face. Zonal structure does not occur in this amphibole.

Inclusions in the katoforite are not as common as in the aegirite-augite. Magnetite in idiomorphic crystals and irregular grains is often included in the amphibole and rarely titanite and apatite. Feldspar is occasionally included in a poikilitic manner.

The maximum extinction angle in sections parallel to the clinopinacoid is 35°. This is measured from the trace of the twinning plane to the direction of vibration of the slow ray and indicates that the position of the amphibole is intermediate between hornblende and arfvedsonite.

In ordinary light the katoforite is light greenish gray in

color. Its characteristic pleochroism is: X = yellowish gray, Y = greenish blue gray, Z = greenish gray, and the absorption is Y>Z>X. In some instances there is a more pronounced blue tone in the pleochroism which indicates a more sodic amphibole. This is especially true in the vibration direction parallel to Y, which in one case is a cadet blue. This latter variety is similar to the hastingsite described by Adams and Harrington[1] from the nephe-

[1]Adams and Harrington, Am. Jour. Sci., Vol. I, p. 210, March, 1896.

line syenite of Dungannon, Hastings County, Ontario. The hastingsite has a smaller axial angle however, and its absorption is Z = Y>X.

The refraction of the amphibole is somewhat lower than that of the pyroxene. Its birefringence is .008, which is so low that it is compensated by the quarter undulation mica plate. The dispersion is inclined with $\rho > v$.

Fracturing of the rock has broken and crushed some of the amphibole grains, which are oriented irregularly along the plane of fracture that has been healed by recrystallization.

Primary corrosion does not seem to have affected the katoforite to any considerable extent. In some cases the amphibole is fresh and shows good idiomorphic outlines and relationships that clearly prove it is primary in origin, but in many cases it is altered to such an extent that its primary or secondary origin is undeterminable. Its alteration is accompanied by the formation of magnetite, lepidomelane, epidote and calcite.

The katoforite is often intergrown with the aegirite-augite or forms a nucleus, with the pyroxene as an irregular border around

it.[1]

[1] W. C. Brogger, Die Eruptivgesteine des Kristianiagebietes I, pp. 27-39, 1894.

QUARTZ:- Quartz occurs as anhedral grains filling the interstices between the feldspars. Its average diameter is about .5 mm. Inclusions in the quartz consist of very small amounts of feldspar, aegirite-augite, magnetite and apatite. Minute submicroscopic black dots are very common as well as liquid and gas inclusions. These have an irregular arrangement in the quartz and only rarely do they exhibit a linear arrangement.

ACCESSORY MINERALS:- Magnetite is present in the granite in very small proportion. Its habit varies from idiomorphic grains to those exhibiting shapeless outlines. It is often associated with the femic minerals, usually as inclusions in the aegirite-augite and katoforite. As a secondary mineral, it is derived from the alteration of the above amphiboloids, in which case it is scattered along the cleavage cracks of the aegirite-augite and katoforite in irregular shred-like masses.

Titanite occurs in euhedral outlines as inclusions in the feldspar, aegirite-augite and katoforite. It is in short diamond-shaped outlines to slender prisms with sharp terminations. The color is a yellowish gray and the pleochroism varies from colorless to pale yellow.

Apatite is very sparingly present as inclusions in feldspar and amphiboloids in euhedral to subhedral grains and as irregular particles between the feldspars.

Structure.

The granite is generally massive, although in some places it is traversed by joints and fractures, which separate the rock into blocks of irregular shape and size. This roughly parallel jointing was mistaken for bedding by some of the earlier geologists who visited the region and probably influenced N. H. Winchell to conclude that the granite is a sediment metamorphosed in situ. Grant showed, however, that there is no difference in the various "layers" and that there is not even a parallel arrangement of the minerals in the granite. Crushing and extensive granulation of the granite is not indicated either in the field or in the study of thin sections. In many cases the extensive development of the feldspars with subhedral outlines gives a subporphyritic aspect to the rock. With an increase in the euhedral character of the feldspar and the production of a second generation of minerals as a ground mass in which the euhedral crystals are embedded, the rock takes on the porphyritic aspect sometimes characteristic of the border of an igneous mass.

III. THE GRANITE PORPHYRY.

General Description.

The granite porphyry in its most typical development is composed of white or pink feldspar crystals in a dark gray felsitic ground mass. Small black grains and patches of what appears to be hornblende or augite are visible in some cases and occasionally small black mica flakes are seen. The maximum diameter of the feldspar crystals is 25 mm., but there are all gradations in size down to those having a diameter of 1 mm. or 2 mm. The habit of the feldspar varies from equidimensional grains to prismatic and tabular. Zoning is apparent on the fractured feldspar grains even in the hand specimen. The groundmass varies from a dark gray color in the rocks having a more pronounced porphyritic texture to a light gray or pink as the rock becomes more granular. In the most distinctive porphyries the proportion of the groundmass may reach about 50 per cent but it gradually diminishes as the rock becomes more and more granular in texture.

In thin section the porphyry is seen to be composed of albite, aegirite-augite, hornblende, actinolite, lepidomelane, quartz, apatite, titanite, and magnetite. The apatite, titanite, and magnetite were the first minerals to crystallize, followed by the aegirite-augite. The albite probably started to separate out early in the process of crystallization of the magma, as the crystals often attain considerable size in proportion to the pyroxene. Both the albite and the pyroxene show zonal growth, which indicates that the magma was changing in composition during

the process of crystallization. The nucleus of the albite is more basic than the outer portion, while the interior of the pyroxene is augite. The calcium molecule withdrawn from the molten solution in the formation of the more basic central portion of the albite crystals would decrease the supply of calcium for the formation of the augite molecule, hence the outer zones of the pyroxene become richer in the acmite molecule, forming aegirite-augite.

The relative proportions of the minerals in a representative specimen of the porphyry taken from the point on the S. W. $\frac{1}{4}$ of the S. W. $\frac{1}{4}$ sec. 29, T. 65 N., R. 6 W. are indicated below.

Mineral	Per cent
Albite	35.0
Aegirite-augite	8.2
Lepidomelane	2.8
Apatite	0.5
Magnetite	0.3
Titanite	0.1
Groundmass	53.1
	100.0

While quartz does not occur as phenocrysts in the porphyry, yet it is present in the groundmass in small amounts. Its presence in conjunction with the acid albite, classes this rock as a granite porphyry rather than as a syenite porphyry.

Description of Individual Minerals.

ALBITE:- The albite is euhedral to subhedral in outline with elongation parallel to the "c" crystallographic axis. The unit prismatic faces and the brachy- and macro-pinacoidal faces are well developed, also the basal plane and the rear hemidome, I01.

Cleavage parallel to the basal plane is much more common than that parallel to the brachypinacoid.

There is considerable variation in the size of the albite grains but in the typical porphyry the average diameter is about 6 mm. All variations in size exist between this and the size of the feldspar grains in the typical granite, which have an average diameter of about .75 mm.

Twinning according to the albite and pericline laws is very common and furnishes a ready means for the determination of the feldspar.

Zonal arrangement of the albite is very often observed. The central portion of the crystal is generally more basic than the outer portion and is twinned according to the albite and pericline laws. Surrounding this, with a more or less definite line of demarcation, is a more acid albite. Two and sometimes three rather distinct zones are developed. Sometimes there is a gradual change in the composition from the central portion of the crystal outward without definite delimitations of the zones. The outer zones very often consist of untwinned albite that has a fresher appearance than the central portion. Inclusions of aegirite-augite, titanite, magnetite and apatite are present in the albite. Of these the most abundant is aegirite-augite with euhedral to subhedral outlines, while titanite, magnetite and apatite are very sparingly included.

The extinction angles on the albite measured in the zone perpendicular to 010 range from 12°- 17° which indicates a variation in the albite from Ab_{90} An_{10} to Ab_{97} An_3. Extinction angles on sections parallel to the brachypinacoid, measured from the trace of the basal cleavage, gave values varying from 19° - 20°.

This also indicates a very acid plagioclase and checks with the values obtained in the zone at right angles to the brachypinacoid. The pericline twinning aids in the orientation of the feldspar sections and the angle between these lamellae and the trace of the basal cleavage also indicates an acid plagioclase. The more basic central portions of zoned albite crystals show the minimum extinction angles, which increase in value to a maximum in the outermost zone.

The indices of refraction are in nearly all cases lower than that of Canada balsam. The only exception to this is in the case of the more calcic inner portion of some of the larger albite crystals where one of the indices appears to be higher than that of the Canada balsam, as shown by the movement of the Becke line.

Fracturing of the albite crystals is frequently observed, especially where the porphyry is in contact with the intruded rock, or where there are indications of flow structure in the porphyry. In such cases broken and angular fragments of the feldspar are scattered through the groundmass, near the crystal from which they were broken. The magma, which later crystallized as the groundmass, must have been highly viscous when this fracturing took place, since the fractured particles were able to move only very short distances and there is no indication of resorption of these particles by the enclosing magma.

Primary corrosion of the albite was limited. The albite crystals generally have well developed crystallographic boundaries, but occasionally small embayments in the boundaries indicate a corroding action by the magma.

The albite appears cloudy or turbid in consequence of alteration. The decomoosition products consist of a fine grained gray aggregate of kaolin and calcite which, in the case of the zonally arranged feldspar, marks out the zones by a more complete decomposition in the central portion as indicated by the darker tone of the alteration products.

AEGIRITE-AUGITE;- The optical properties of the pyroxene in the porphyry have been described by U. S. Grant[1], whose results

[1]U. S. Grant, 21st Ann. Rept. Geol. Nat. Hist. Survey Minn., pp. 44-48, 1893.

may be summarized as follows: The habit of the augite is euhedral and equidimensional with the prismatic planes well developed and the terminal planes occasionally lacking. The average diameter of the grains is about .5 mm. Traces of the cleavage are present, and in one case a parting parallel to the basal plane was observed. Zonal arrangement is common, in which case, the nucleus of the crystal is colorless or of lighter green color than the outer rim. There is occasionally a gradual transition from the colorless cores to the green borders, but generally the line of separation is rather distinct. Extinction angles of the colorless centers, measured from the trace of the cleavage to the direction of vibration of the slow ray on sections parallel to the clinopinacoid, are as high as 58° but are usually lower, while the extinction angles on the green borders are about 68°. In transmitted light the augite is colorless to light green. The pleochroism is for X and Y, bottle green, and for Z, yellowish green. The index of refraction and the birefringence of the green rims is lower than that of the colorless central portions. The above facts indicate that the green rims

contain more of the acmite molecule than the colorless parts. On the assumption that the augite represents an isomorphous mixture of diopside, hedenbergite, acmite and fassaite, the proportions of these minerals calculated from a chemical analysis of the augite is as follows:-

Diopside	47 per cent
Hedenbergite	27 " "
Acmite	21 " "
Fassaite	5 " "

The proportion of the acmite molecule in this pyroxene, as is indicated by the above description, places it in a position intermediate between augite and aegirite, hence the term aegirite-augite is used for this mineral.

The alteration products of the aegirite-augite are a fibrous actinolite, lepidomelane, calcite, epidote and magnetite. The incipient stage of alteration is characterized by a shred-like growth of actinolite from the ends of the pyroxene crystals. As the alteration proceeds, the entire crystal of aegirite-augite is replaced by the secondary amphibole, which is often accompanied by the formation of some lepidomelane and magnetite. Alteration to epidote and limonite was observed in a few cases; in others the pyroxene was replaced by an aggregate of epidote, magnetite and calcite.

HORNBLENDE:- The hornblende has euhedral to subhedral outlines which indicate that it is probably of pyrogenetic origin. The grains are usually elongated parallel to the prismatic sections. The pyramid terminations represented are the basal plane and an orthodome. In the prismatic zone the forms present are the unit prism and the orthopinacoid.

The grains have an average diameter of about .5 mm.

Twinning is occasionally observed with 100 as the twinning plane and composition face.

Zonal arrangement in the hornblende is sometimes observed. The central portion is lighter in color but shows a gradual transition to the darker brown of the border.

The pleochroism is X = yellowish, Y = brown, Z = greenish brown to emerald green.

This hornblende has a birefringence of approximately .018.

Extinction angles on sections parallel to 010 have a maximum value of about 22°. In grains showing zonal arrangement, the extinction angle of the lighter colored central portion is higher than that of the darker colored margin.

Alteration is generally initiated by the formation of a fibrous actinolite on the ends of the hornblende, accompanied by the formation of magnetite. Eventually the hornblende is entirely replaced by actinolite.

ACCESSORY MINERALS:- Apatite is the most abundant of the

accessory minerals. It has euhedral outlines and forms equidimensional or elongated grains that are found as inclusions in the albite or scattered irregularly through the groundmass. Magnetite is generally present in small euhedral grains in the groundmass. Titanite may occur as inclusions in the albite, but more often is seen in euhedral grains throughout the groundmass. Quartz in very limited quantities is sometimes observed in irregular grains, but the fine grain of the groundmass prevents a determination of its abundance.

THE GROUNDMASS:- The size of the particles constituting the groundmass varies from submicroscopic grains to those which can be determined under the microscope with high magnification. It consists of very small particles of untwinned feldspar and quartz. The feldspar is probably a soda-microcline, since microchemical tests on small fragments of the groundmass indicated the presence of both sodium and potassium.

Structure.

The granite porphyry in its typical development around the border of the intrusive mass contains euhedral, equidimensional to elongated crystals of white or light reddish feldspar up to 6 mm. in diameter, and subhedral to euhedral, equidimensional crystals of black pyroxene of much smaller size than the feldspar, in a dense dark gray felsitic ground mass. Occasionally a few small mica plates are scattered through the ground mass, especially near the contact.

Flow structure is developed in a few localities on the peri-

phery of the igneous mass as indicated by the sub-parallel arrangement of the elongated feldspar phenocrysts. Generally, however, there is a random orientation of the feldspar phenocrysts with no indication of flowage. The equidimensional habit of the pyroxene crystals prevents them from bearing out the parallel arrangement shown by the feldspar.

With increasing distance from the border toward the central area of the intrusive, there is a decrease in the quantity of the groundmass, resulting in a more granular rock. This increased degree of crystallinity of the rock is accompanied by a lighter color due to the decrease in the dense dark gray groundmass and the increase in the lighter colored feldspar of microscopic size.

IV. RELATION OF THE GRANITE TO THE PORPHYRY.

The field work indicated that the granite and the porphyry crystallized from the same magma and were not separate intrusions as suggested by Grant. In making numerous sections across the outcrops of the intrusive, there appeared to be all transitions from a porphyritic phase on the periphery to a granular rock in the central portion of the igneous mass, and in no instance was there any indication of a distinct contact between the granite and the porphyry nor of dikes of the latter cutting the granite. In making a section from the little bay in the N.E.¼ of the S.W. ¼, sec. 36, T.65 N., R. 7 W., westward along the south side of the lake, specimens were taken which, even in the field, indicated a transition from the typical porphyry to the normal granite. Microscopical examination of these specimens and other specimens from various places bears out the field evidence in a very decisive manner.

The modes of representative specimens of the granite and the porphyry and of rocks showing transitions between them are given in tabular form below.

Comparison of Modes of Granite and Porphyry.

	I	II	III	IV	V
Quartz	0.00	0.00	1.54	2.05	4.42
Feldspar	32.40	40.15	53.68	81.81	83.49
Aegirite-augite	10.10	10.65	10.65	8.91	7.11
Katoforite	0.00	0.00	4.76	5.47	3.01
Titanite	0.60	0.10	0.25	0.23	1.07
Magnetite	0.60	1.30	0.00	1.29	0.73
Apatite	0.60	0.80	0.12	0.24	0.17
Biotite	3.00	0.00	0.00	0.00	0.00
Groundmass	52.70	47.00	29.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00

I is a typical porphyry with medium-sized feldspar phenocrysts, in a dark gray felsitic groundmass from the S.W.$\frac{1}{4}$ of the S.W.$\frac{1}{4}$, sec. 29, T. 65 N., R. 6 W.

II is a porphyry showing larger feldspar phenocrysts than I, but having the same dense dark gray felsitic groundmass. This specimen was taken from the eastern side of the small lake in the central part of the eastern $\frac{1}{2}$ sec. 36, T. 65 N., R. 7 W.

III is a grayish pink rock with small pink or white feldspar phenocrysts in a light gray groundmass. Small black dots of aegirite-augite are visible in the groundmass. It is from the point in the N.W.$\frac{1}{4}$ of the S.W.$\frac{1}{4}$ of sec. 3, T. 64 N., R. 7 W.

IV is medium-grained, pink rock with subhedral pink feldspars and small black grains of aegirite-augite. The rock is subporphyritic in appearance, but contains no groundmass. This rock occurs in the S.W.$\frac{1}{4}$ of the N.W.$\frac{1}{4}$ sec. 1, T. 64 N., R. 7 W., just east of the small lake on the line between sec. 1 and 2.

V is a fine-grained, pink granular rock from the S.W.$\frac{1}{4}$ of the S.W.$\frac{1}{4}$, sec. 1, T. 64 N., R. 7 W. Small irregular black grains of aegirite-augite of somewhat smaller size than the pink feldspar grains are present in small amount. This rock is representative of the medium to fine-grained granite which makes up the central portion of the granite mass.

There is a gradual variation in the percentage of quartz from 4.42 per cent in the granite to practically nothing in the porphyry. While there may be a small percentage of quartz in the groundmass in the porphyry, yet measurements made on sections with increasing amounts of groundmass showed a decrease in the percentage of quartz. Observations made on the groundmass of a number of sections with a high power objective indicated a very small amount of quartz.

The feldspar in the central portion of the granite mass is typically an intergrowth of albite and soda-microcline with a small amount of albite. The percentage of the albite increases in proportion to the albite-soda microcline intergrowth with increase in the distance from the central portion of the granite mass, until the latter is entirely replaced by albite in the

typical porphyry, on the periphery. The albite which occurs in small amount in the normal granite has the same habit and type of twinning as the albite in the typical porphyritic phase.

The characteristic pyroxene of the granite is aegirite-augite and in the porphyritic phase it is typically composed of a central zone of augite with an outer zone of aegirite-augite. This variation is in accordance with the variation in the feldspar from a more basic central portion to a more sodic outer zone, and also agrees with the normal progress of crystallization of a magma. The crystallization of the pyroxene started with the formation of a mineral ranging in the isomorphous pyroxene series from basic diopside to augite, and as the magma was depleted of calcium, not only by the formation of augite, but by the formation of basic albite, the outer zone of the pyroxene became more alkaline by an increase in the proportion of the acmite molecule and resulted in the formation of aegirite-augite. The pyroxene of the normal granite is thus aegirite-augite as would be expected, since the magma from which the normal granite crystallized was too alkaline to permit the formation of a more basic pyroxene.

The amphibole in the granite is katoforite, which corresponds in its position in the amphibole series to the place occupied by aegirite-augite among the pyroxenes. The katoforite is developed in greatest abundance in the granite and occurs in decreasing amounts as the rocks become more porphyritic. In the typical porphyry the katoforite seems to be replaced by aegirite-augite or in a few instances by the development of a small amount of brown hornblende. The development of the more basic amphibole, hornblende,

in the porphyry would be in accordance with the development of the more basic pyroxene, augite.

In one or two sections from the porphyry in contact with the slates, a small quantity of lepidomelane is present. This may be due to the assimilation of a very small amount of alumina from the slate, in which case biotite may form instead of hornblende. When the sum of the alkalies and the calcium in the magma exceeds the alumina, then the excess of CaO goes into the formation of hornblende, but when the alumina is in excess, then the iron and magnesium enter into biotite. The small amount and limited occurrence of the biotite would seem to indicate that the magma was not sufficiently hot or was too viscous, to permit any extensive assimilation of the slate.

From the field relationships and the chemical and mineralogical similarity of the granite and porphyry, the evidence is conclusive that there are all gradations between the normal granite and porphyry.

The differences in texture are due to the conditions under which the magma cooled. Along the border of the intrusive, chilling took place rather suddenly and the rapidly crystallizing border froze on to the country rock. That very little if any assimilation of the country rock took place after the magma was intruded into its present position is indicated by the lack of contact action on the slates, and the sharp line of the contact.

In a few cases a movement of the molten magma before complete solidification is shown by the arrangement of the albite phenocrysts in the porphyry in a direction approximately parallel to the

periphery. The viscosity of the magma was probably too great, however, to permit more than a small amount of differentiation of the granite magma in its present location.

V. COMPARISON OF THE CACAQUABIC GRANITE WITH THE SNOWBANK SYENITE AND GIANTS RANGE GRANITE.

There is a very marked similarity between the Cacaquabic granite and some of the other intrusives of Lower or Middle Huronian age in the Lake Superior region, as for instance, the Snowbank syenite and the Giants Range granite. In the following tables are the chemical analyses of these rocks and their corresponding norms. I is the Cacaquabic granite, analyzed by J. M. Lindgren; II is the Snowbank syenite analyzed for C. S. Ross[1] by J. M. Lindgren; III is a quartz porphyry from the Giants Range granite[2].

[1] C. S. Ross, Unpublished Thesis, University of Illinois.

[2] U. S. Grant, 21st Ann. Rept. Geol. Nat. Hist. Survey Minn., p. 43, 1893.

Analyses of Granites and Syenite of Lower or Middle Huronian Age.

	I	II	III
	%	%	%
SiO_2	65.16	59.63	69.70
Al_2O_3	15.85	16.11	18.72
Fe_2O_3	1.20	4.87	0.65
FeO	1.18	0.87	0.79
MgO	1.75	3.16	0.45
CaO	2.40	5.02	2.25
Na_2O	5.84	5.83	5.01
K_2O	5.60	5.45	1.08
TiO_2	0.24	0.62	----
P_2O_5	0.07	0.58	----
H_2O	0.66	0.78	0.71
Total	99.98	100.65	99.96

Calculation of Norms of Granites and Syenite of Lower or Middle Huronian Age.

	I	II	III
	%	%	%
Quartz	4.08	1.50	28.14
Orthoclase	33.36	20.57	10.10
Albite	49.25	49.25	42.44
Anorthite	0.56	7.51	11.12
Corundum	0.00	0.00	4.49
Salic	87.25	78.83	96.20

	I	II	III
Diopside	8.99	10.58	0.00
Hypersthene	0.83	3.00	2.02
Magnetite	1.86	0.93	0.93
Hematite	0.00	4.32	0.00
Ilmenite	0.46	1.22	0.00
Titanite	0.00	0.00	0.00
Apatite	0.00	1.34	0.00
Femic	12.14	21.39	2.95
Salic	87.25	78.83	96.20
H_2O	.66	0.78	0.71
Total	100.05	101.00	99.86

The Snowbank syenite is a more basic rock than the Cacaquabic granite as is shown by the smaller percentage of quartz and the larger proportion of the femic minerals. The proportion of the anorthite molecule is also considerably higher in the Snowbank syenite.

The Giants Range granite has a much higher percentage of quartz and a much smaller amount of femic minerals than either the Cacaquabic granite or the Snowbank syenite. The extremely large percentage of normative corundum in the Giants Range granite with the attendant calculation of all of the calcium into anorthite seems rather anomolous when the large percentage of free quartz is taken into consideration. These discrepancies render the validity of the analysis rather questionable.

The sodic character of all three of these rocks as indicated by their analyses, is shown in the relatively high percentage of the albite molecule in the norm. In the Cacaquabic granite, however, the percentage of normative orthoclase shows that this rock is more nearly allied to the sodapotassic rocks than to the predominantly sodic rocks.

The mineralogical relationships of these intrusions brings out their analogy much more clearly than is indicated by the chemical analyses and norms. N. H. Winchell[1] noted the similarity of the

[1]N. H. Winchell, IVth Final Rept. Geol. Nat. Hist. Survey Minn., Vol. IV, pp. 287-289, 1899.

rocks in the Snowbank and Cacaquabic Lake regions. He states that in each region there is a porphyry which becomes granitic and a granite which becomes augitic, and thinks that the difference is due to the character of the sediment which was fused to form the granite and porphyry.

Both the Cacaquabic granite and the Snowbank syenite are characterized by an intergrowth of sodic and potassic feldspars. In the Snowbank Lake region the sodic part of the intergrowth is often an albite-oligoclase[1], but in the Cacaquabic Lake granite,

[1]C. S. Ross, Unpublished Thesis, University of Illinois.

this part of the intergrowth is a practically pure albite. This is to be expected since the Snowbank syenite is a little more basic in character than the Cacaquabic granite. Both of these rocks contain aegirite-augite, often with a central zone of augite bordered by aegirite-augite. Titanite is also abundant in both cases as an accessory constituent.

The most striking similarity between the Cacaquabic granite and the Giants Range granite is their common possession of aegirite-augite as the dominant pyroxene. Hornblende is developed in greater abundance in the latter granite but both have perthitic development of feldspars and also considerable titanite.

These rather striking similarities of the Cacaquabic granite,

Snowbank syenite and Giants Range granite indicate that they may have crystallized from the same parent magma or from very closely related magmas. Such differences as are found now may be readily explained on the basis of differentiation in their present position, or a variation in the rate of cooling. These factors would be influenced by the size of the intrusion, initial heat, amount of cover, character of the country rock, and amount and character of volatile constituents.

VI. CONTACT METAMORPHISM.

Effect of Granite and Porphyry on Knife Lake Slate.

The granite was not found in contact with the Ogishkeo conglomerate or the Knife Lake slate at any place in the region. This is in accordance with the fact that the normal granite is found only in the central part of the intrusive and represents the final stage of consolidation of the magma.

Several contacts of the porphyry with the Knife Lake slate were found and specimens were collected across the contacts. One such section was made in the N.W.¼ of the S.E.¼, sec. 36, T. 65 N., R. 7 W. At a distance of 300 feet from the contact the porphyry is granulated to a slight extent and a small amount of corrosion of the albite phenocrysts is indicated by the small embayments around their edges. Secondary calcite is now abundantly developed. At a distance of 50 feet from the contact the only noticeable difference in the rock, as seen in thin section, is an increase in the amount of the granulation. The rock has a light grayish pink color and appears almost saccharoidal in texture. A specimen of dark gray medium grained schistose graywacke 15 feet from the contact shows no evidence of contact action. There is no apparent recrystallization of any of the clastic fragments, nor are there any injected stringers of porphyry in the slate.

A specimen showing direct contact of the porphyry and the slate from the S. W. corner of the island in the N. E. ¼ of the S. W. ¼, sec. 36, T. 65 N., R. 7 W., showed no apparent contact action in the hand specimen. The line separating the porphyry

from the slate is very sharp, and traces of the bedding lamellae in the slate can be followed right up to the contact. In thin section there is no indication of recrystallization of the slate. The porphyry is crushed and granulated along the line of contact, due to a differential movement of the viscous magma a slight distance away from the margin after the marginal portion had become chilled sufficiently to "freeze" on to the slate.

On the point in the N. W. ¼ of the N. W. ¼ of sec. 3, T. 64 N., R. 7 W. another contact of the porphyry and the slate is seen. Here again there is a very sharp line of contact between the two. Microscopical examination of a slide showing this contact indicated no recrystallization of the slate, which agrees with the evidence cited from other contacts.

Series of specimens across the contact of the porphyry and the slate were studied from the eastern side of the lake in the N. E. ¼ of the S. E. ¼ sec. 36, T. 65 N., R. 7 W., in the S. E. ¼ of the S. W. ¼ sec. 31, T. 65 N., R. 6 W., and in the S. W. ¼ of the S. W. ¼ sec. 29, T. 65 N., R. 6 W. In all of these cases there is the same lack of contact action of the porphyry on the slate as observed in the contacts described above.

VII. SUMMARY AND CONCLUSIONS.

The points brought out in the foregoing pages may be summarized as follows:

1. The feldspar in the Cacaquabic granite is an intergrowth of albite and soda-microcline. It was formerly described as anorthoclase.

2. Aegirite-augite is the pyroxene in the granite. The zonal growth of pyroxene with a central core of augite and an outer rim of aegirite-augite is confined to the porphyritic border phase of the granite.

3. The primary amphibole in the granite is katoforite.

4. This granite belongs to the soda-potash class of alkaline granites low in quartz. Formerly it was regarded as belonging to the class of rare, predominantly sodic granites.

5. In the porphyritic border phase of the granite, the feldspar is an acid albite with well-developed zonal structure.

6. The porphyry is a border phase of the granite and does not represent a separate intrusive of later date.

7. A comparison of the Snowbank syenite and Giants Range granite with the Cacaquabic granite indicates that these intrusives were derived from the same parent magma.

8. At the contact of the porphyry with the Knife Lake slate, there is no evidence of contact metamorphism.

VIII. BIBLIOGRAPHY.

1. Adams, F. D., and Harrington, B. J., On a new alkali hornblende and a titaniferous andradite from the nepheline-syenite of Dungannon, Hastings County, Ontario: Amer. Jour. Sci., vol. 1, pp. 210-218, 1896.

2. Brögger, W. C., Die gesteine der grorudit-tinguait-serie: Die Eruptivgesteine des Kristianiagebietes, 1, pp. 27-39, 1894.

3. Clements, J. Morgan, The Vermilion iron-bearing district of Minnesota; U. S. Geol. Survey Mon. 45, 1903.

4. Daly, Reginald Aldworth, Igneous rocks and their origin, 1914.

5. Eskola, Pentti, On the petrology of the Orijarvi region in southwestern Finland: Bulletin de la commission geologique de Finlande, No. 40, 1914.

6. Grant, U. S., Note on an augite soda-granite from Minnesota: Am. Geologist, vol. 11, pp. 383-389, 1893.

7. Grant, U. S., Minnesota Geol. and Nat. Hist. Survey, 20th. Ann. Rept., pp. 69-82, 1893.

8. Grant, U. S., The geology of Kekequabic Lake in northeastern Minnesota with special reference to an augite soda-granite: Minnesota Geol. and Nat. Hist. Survey, 21st. Ann. Rept., pp. 5-59, 1893.

9. Iddings, Joseph P., Igneous rocks, vol. 1 and 2, 1909.

10. Johannsen, Albert, Manual of petrographic methods, 1914.

11. Lane, A. C. Porphyritic appearance of rocks: Bull. geol. Soc. America, vol. 14, pp. 385-406, 1902.

12. The coarseness of igneous rocks and its meaning; Am. Geologist, vol. 35, pp. 67-72, 1905.

13. Lincoln, F. C., and Rietz, H. L., The determination of the relative volumes of the components of rocks by mensuration methods: Ec. Geol., vol. 8, No. 2, pp. 120-140, 1913.

14. Rosiwal, August, Uber geometrische gesteinsanalysen. Ein einfacher weg zur ziffernmässigen feststellung des quantitativverhaltnisses der mineralbestandtheile gemengter gesteine, Verh. d. k. k. geol. Reichsanst., pp. 143-175, 1898.

15. Ross, C. S., Unpublished thesis, University of Illinois.

16. Johannsen, Albert, Manual of petrographic methods, 1914.

17. Wadsworth, M. E., Preliminary description of the peridotytes, gabbros, diabases and andesytes of Minnesota: Minnesota Geol. and Nat. Hist. Survey, Bull. No. 2, pp. 124-125, 1887.

18. Washington, H. S., Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 99, p. 220 and 1162, 1917.

19. Winchell, A., Minnesota Geol. and Nat. Hist. Survey, 15th. Ann. Rept., pp. 148-156 and 179-180, 1887.

20. Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, 10th. Ann. Rept., pp. 92-93, 1881.

21. Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, 15th. Ann. Rept., pp. 361-369, 1887.

22. Winchell, N. H., Minnesota Geol. and Nat. Hist. Survey, 16th. Ann. Rept., pp. 100-108, 1888.

23. Winchell, N. H., The geology of Minnesota: Minnesota Geol. and Nat. Hist. Survey, Final Rept., Vol. 4, 1899, vol. V, 1900.

APPENDIX.

Biography.

Place and date of birth:

Waverly, Illinois, August 4, 1890.

Education:

Springfield, Illinois, High School, 1905-1909,

University of Illinois, 1910-1915.

Degrees:

A. B., University of Illinois, 1915,

A. M., University of Illinois, 1915.

Teaching experience:

Assistant in Geology, 1915-1916.

Professional experience:

Field Assistant, Illinois State Geological Survey, Summer 1914,

Geologist, Wichita Natural Gas Co., Bartlesville, Oklahoma, June, July, 1916,

Field work in Vermilion and Mesabi Iron Ranges of Minnesota, August, September, 1916,

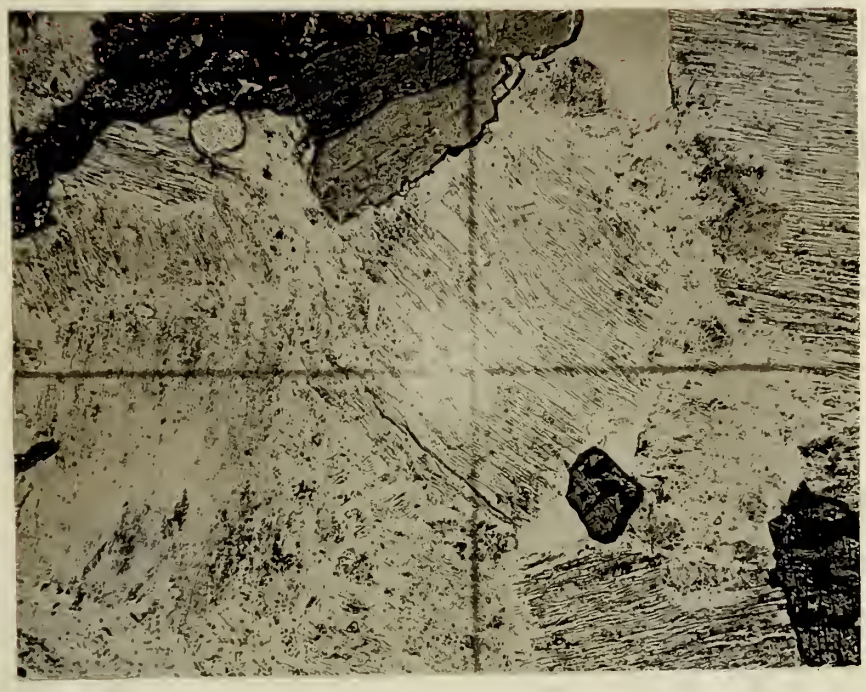
Stratigraphic and structural Geology, Sun Oil Co., Philadelphia, Pennsylvania, Summer, 1917.

Plate I.

A. Photomicrograph showing micropertnitic intergrowth of albite and soda-microcline in Cacaqusbic granite. Parallel light. Magnified 125 diameters.

B. Same as above. Crossed nicols.

Plate I.



A.

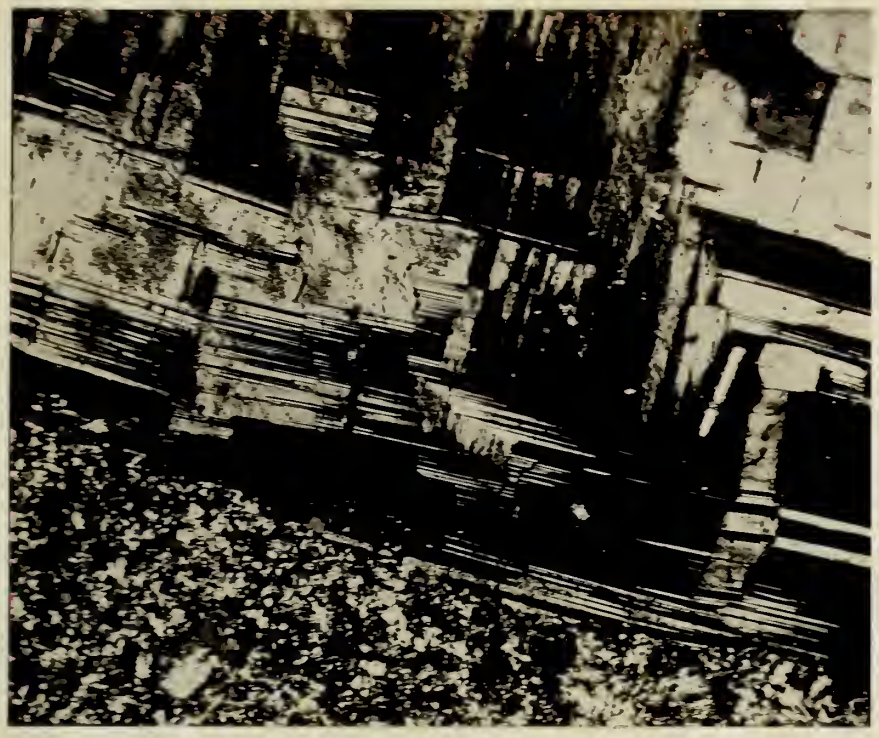
B.

Plate II.

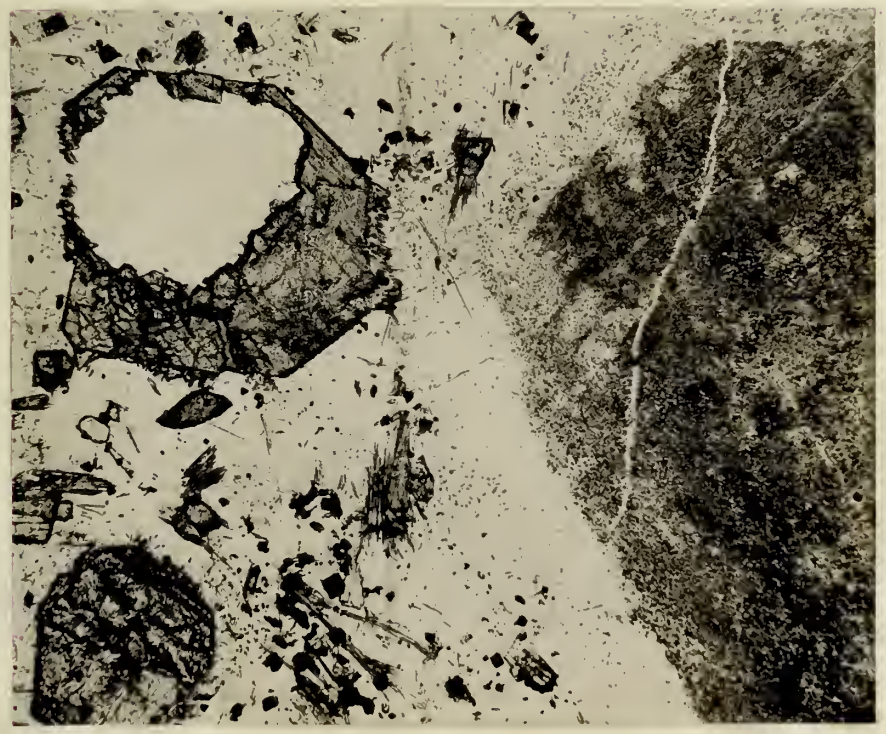
A. Photomicrograph exhibiting albite and pericline twinning in albite phenocrysts in granite porphyry. Crossed nicols. Magnified 70 diameters.

B. Photomicrograph showing eunedral outlines of albite and aegirite-augite in granite porphyry. Zonal arrangement of the feldspar is indicated by the degree of alteration, the central portion being much more altered than the border.

Plate II



A



B

Plate III

A. Western part of Cacaquabic Lake. Taken from hill on north side of lake. Shows numerous islands which are characteristic of the lakes in this region.

B. Eastern part of Cacaquabic Lake. Taken from hill on north shore of lake near the "narrows".

Plate III

A

B

Plate IV

A. Small lakes north of Cacaquabic Lake.

B. Bluff of Ogishkoe conglomerate on south side of Cacaquabic Lake near "narrows".

Plate IV

A

B

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